Nitrification Treatment of Swine Wastewater

Under Cold Temperatures

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   Abstract. In addition to N load, cold weather nitrification is an important consideration for stabilized performance of biological processes applied to continuous animal production systems. A winter simulation experiment was conducted in the laboratory to evaluate performance of immobilized bacteria for treatment of swine wastewater under cold weather conditions. Bench fluidized reactors (1.2 L) containing 120 mL polyethylene glycol nitrifying pellets (10% v/v) were operated under continuous flow using swine wastewater containing 330 to 450 mg NH_4-N/L, and 140 to 290 mg BOD_5/L. Water temperature in the reactors was controlled using a refrigerated circulating bath with car antifreeze liquid. Starting at 15^oC and a hydraulic residence time (HRT) of 18 hrs, wastewater process temperatures were decreased 2.5-3^oC every three weeks to a low of 3^oC. Ammonia was completely removed in all of these runs, which precluded calculation of nitrification potential. For this reason, the continuous flow experiment was repeated using higher N loads obtained with HRT of 12 hrs, each temperature run lasting 2 weeks. In addition to continuous flow, batch tests were also done at various process temperatures to determine nitrification rate at cold temperatures with a different method, each batch temperature test lasted 8 hrs and was replicated three times. As expected, the effect of process temperature on nitrification rate was well described by an exponential function. But nitrification activity was not severely affected by the lower temperatures in the experiment (3-5^oC) as previously thought, indicating acclimation of the entrapped nitrifying bacteria to the winter conditions. The temperature coefficient (Q_{10}) obtained was consistent between continuous flow and batch conditions and averaged 1.41. This means that nitrification rate decreased only by 29% for each 10^oC decrease in water temperature. This decrease is significantly different than the Q_{10} of 3 (70% rate decrease per 10^oC) commonly used to predict activity of nitrifying bacteria under cold weather conditions. Thus, the immobilized technology appears well suited for nitrification of high-ammonia livestock wastewater under cold weather conditions.

   Keywords: high ammonia wastewater, biological nitrogen removal, nitrification treatment, immobilized bacteria, alternative technologies.

Introduction

   In addition to nitrogen (N) load and hydraulic residence time (HRT), cold weather nitrification is an important consideration for stabilized performance of biological N removal processes applied to wastewater treatment of animal production systems. Temperature is a critical consideration for nitrifying bacteria because of their low specific growth rate values (Grady et al., 1999). The efficiency of the nitrification process can be increased by increasing the nitrifiers' retention time independent from the wastewater retention time. In most cases, this is done by immobilization of nitrifiers. One advantage of this technology is that increased wastewater flow is possible with minimal washout of nitrifying bacteria. Advances in biotechnology using immobilization technology have shown that higher nitrification efficiencies are possible through the entrapment of cells in polymer gels. The nitrifiers are entrapped in 3- to 5-mm polymer gel carriers (pellets) permeable to NH_4^+, oxygen, and carbon dioxide needed by these microorganisms,

resulting in a fast and efficient removal of N. The successful application of these gel carriers for nitrification treatment of municipal wastewater has been demonstrated using both natural polymers such as calcium alginate (Lewandowski et al., 1987) and synthetic polymers such as polyethylene glycol, PEG (Tanaka et al., 1991), or polyvinyl alcohol, PVA (Furukawa et al., 1994). Pellets made of synthetic polymers are superior to natural polymers in terms of strength and durability; their estimated life span is > 10 years. Tanaka et al. (1991) reported nitrification rates three times higher than those of the conventional activated sludge process. Vanotti and Hunt (2000) found that immobilized pellets are also a useful technology for efficient nitrification treatment of swine wastewater. Their work, however, was done at optimum nitrification temperatures (30°C). There are no reports whether the high performance of these pellets with animal wastewater can be maintained under cold temperature conditions.

We conducted a winter simulation experiment in the laboratory to evaluate performance of immobilized bacteria under cold weather conditions. The laboratory experiment was conducted to support winter operation of a full-scale biological N treatment plant installed in a North Carolina swine farm (Vanotti et al, 2006) that used the same immobilized nitrifying bacteria technology (Biogreen process).

Materials and Methods

Bench fluidized reactors (1.2 L) containing 120 mL (10% v/v) of immobilized PEG pellets (Tanaka et al, 1991) were operated under continuous flow using swine lagoon wastewater from Goshen Ridge farm (units 2 and 3) containing 330 to 450 mg NH_4-N/L, 140 to 290 mg BOD_5/L, and 3185 to 3283 TS/L. The nitrifying pellets (supplied by Hitachi Plant Technologies, Ltd., of Japan) were taken from the nitrification tank of a full-scale plant (Vanotti et al., 2006) installed on the same farm (Figure 1).

Figure 1. Full-scale nitrification tank providing treatment to 4,360-swine farm (Biogreen process). It contained 12 m^3 of nitrifying PEG pellets. The metal structure inside the tank is a stainless steel screen that retained the pellets inside the tank.

Water temperature inside the laboratory reactors was controlled using a submerged temperature probe and a refrigerated circulating bath that pumped chilled car antifreeze liquid through coils inside another insulated water bath chamber that contained the reactors (Figure 2). The influent wastewater was kept at 4°C before treatment using a chilling probe (Figure 3). Flow into the reactor was provided with a peristaltic pump. Optimal aeration conditions were provided with an air-pump and a stone diffuser in bottom of the reactor; dissolved oxygen (DO) concentration was 7.0 to 9.4 mg/L with the highest DO associated with the lowest temperatures.

Starting at 15°C and a hydraulic residence time (HRT) of 18 hrs, wastewater process temperatures were decreased 2.5-3°C every three weeks to as low as 3°C. Water samples were taken twice per week for analyses. Ammonia was completely removed in all of these runs, which precluded calculation of nitrification potential. The continuous flow experiment was repeated using higher N loads obtained with HRT of 12 hrs, each temperature run lasting 2 weeks. At the end of each temperature run, the reactors were

operated briefly in batch mode to determine rates of nitrification under batch conditions. Each batch temperature test lasted 8 hrs and was replicated 3 times. All water analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 1998).
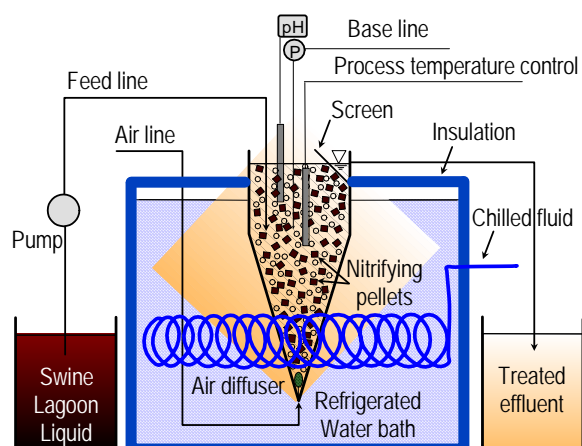

Figure 2. Schematic diagram of the laboratory bioreactor system used to simulate winter conditions. Nitrogen treatment was performed in the fluidized reactor containing nitrifying bacteria entrapped in polyethylene glycol pellets.

Figure 3. Insulated bioreactor used for cold-temperature nitrification experiments (blue box on the right). Circulated, chilled, car antifreeze liquid maintained the process temperature constant at a desired level. Influent wastewater was kept cold using a chilling probe and water bath (red cooler on the left).

Results and Discussion

Results of the continuous (HRT 12 hrs) and batch tests are summarized in Figure 4. As expected, the effect of process temperature on nitrification rate was well described by an exponential function. But nitrification activity was not severely affected by the lower temperatures in the experiment ($3^{o}C$) as previously thought, indicating an acclimation of the entrapped nitrifying bacteria to the winter conditions. Temperature coefficient (Q_{10}) obtained was consistent between continuous flow and batch conditions and

averaged 1.41. This means that nitrification rate of immobilized pellets decreased by 29% for each 10°C decrease in water temperatures. This decrease is significantly different than the Q_{10} of about 3 (70% rate decrease per 10°C) commonly used to predict activity of nitrifying bacteria under cold weather conditions. For example, Characklis and Gujer (1979) and Knowles et al. (1965) reported typical C values of 0.108 and 0.118 °C^{-1}, respectively, for the temperature effect on *Nitrosomonas* with the equation: $k_1 = k_2 \cdot e^{C(T1-T2)}$. Corresponding temperature coefficients Q_{10} values were 2.95 and 3.25. Thus, the immobilized technology with gradual acclimation to colder temperatures appears well suited for nitrification of high-ammonia livestock wastewater because the activity is not severely affected by cold weather conditions.
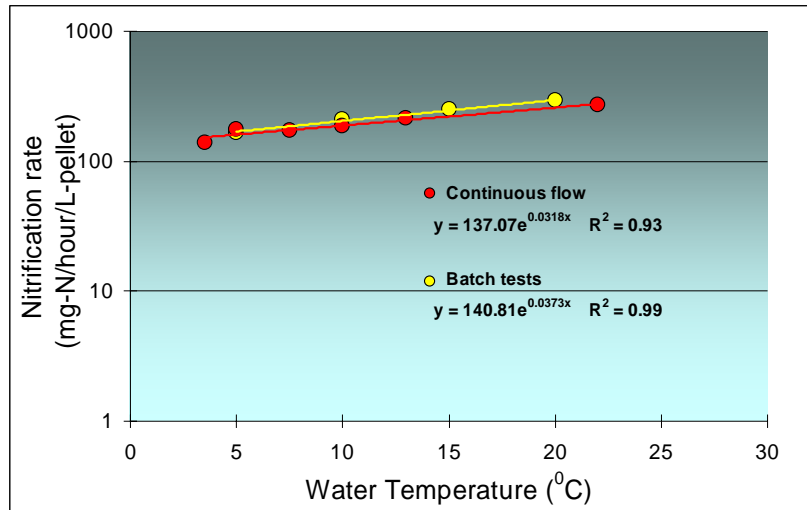

Figure 4. Nitrification rate of swine wastewater with nitrifying pellets as affected by cold water temperatures. Continuous flow data are averages of 2-week runs. Batch test data are averages of three replicates. The reactor contained 10% pellets (v/v).

Nitrification rate of immobilized pellets obtained in the temperature experiments was also calculated for a 12-m^3 pellet-volume used in the full-scale plant (Vanotti et al., 2006). Results of this calculation suggest that immobilized pellet biomass used in the full-scale plant was sufficient to handle both the maximum monthly load of 44.8 kg NH$_4$-N/day and the minimum monthly average water temperature of 11°C that were experienced in the field during a one year full-scale system evaluation. Although the laboratory results indicate the potential nitrification performance under cold weather conditions, the data support the high ammonia removal efficiencies (99%) obtained under field conditions (Vanotti et al., 2006). Combined, they provide a new insight on strategies for biological N removal from confined swine production systems. Our results show that high nitrification efficiencies of swine wastewater can be obtained during cold weather conditions with the use of acclimated nitrifying bacteria entrapped in a PEG gel carrier.

Table 1. Cold weather nitrification of PEG immobilized pellets. Nitrification rate calculated from regression equations in Figure 4. A volume of 12 m^3 of pellets was used in the full-scale demonstration project.

Wastewater Temperature	Nitrification Rate (mg-N/hour/L-pellet)			Average Nitrification Rate (kg-N/day/ m^3 pellet)	Nitrification potential of 12 m^3 pellets. [a] (kg-N/day)
°C	Continuous Flow	Batch Tests	Average		
25	303.5	357.8	330.7	7.94	95.2
20	258.9	296.9	277.9	6.67	80.0
15	220.9	246.4	233.7	5.61	67.2
10	188.4	204.5	196.5	4.71	56.5
5	160.7	169.7	165.2	3.96	47.5

[a] Users of the technology should refer to recommendations by the technology provider (Hitachi Plant Technologies, Ltd., of Japan) for detailed design and engineering considerations.

Conclusions

Poor nitrification during cold weather is often a problem for stabilized nitrification performance of high-strength wastewater in confined livestock production systems. A winter simulation experiment was conducted in the laboratory to evaluate performance of immobilized bacteria for nitrification treatment under cold weather conditions. Nitrification activity was not severely affected by the lower temperatures in the experiment ($< 10^{o}$C) as previously thought, suggesting an acclimation of the entrapped nitrifying bacteria to the winter conditions using a step-wise, gradual decrease in temperatures. Nitrification rate decreased only 29% for each 10°C decrease in water temperature. This is much better than 70% rate decreases per 10°C used to predict activity of nitrifying bacteria under cold weathers. Thus, the immobilized technology with gradual acclimation to colder temperatures appears well suited for nitrification of high-ammonia livestock wastewater.

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References

APHA, AWWA, WEF, 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th ed. Washington, D.C.: American Public Health Association, American Water Works Association, and Water Environment Federation.

Characklis,W.G., and W. Gujer. 1979. Temperature dependency of microbial reactions. In *Kinetics of Wastewater Treatment*. S.H. Jenkins (ed.). Pergamon Press:Elmsford, NY, pp.111-130.

Furukawa, K., S. Ryu, M. Fujita and I. Fukunaga. 1994. Nitrogen pollution of leachate at a sea-based solid waste disposal site and its nitrification treatment by immobilized acclimated nitrifying sludge. *J. Fermentation Bioeng.* 77:413-418.

Grady,C.P.L., G.T. Daigger, and H.C. Lim. 1999. *Biological wastewater treatment, 2nd.ed*. Marcel Dekker, Inc.:New York, NY.

Knowles, G., A.L. Downing, and M.J. Barrett. 1965. Determination of kinetic constants for nitrifying bacteria in mixed culture with the aid of an electronic computer. *J. General Microbiology* 38:263-276.

Lewandowski, Z., R. Bakke, and W.G. Characklis. 1987. Nitrification and autotrophic denitrification in calcium alginate beads. *Water Sci. Tech.* 19:175-182.

Tanaka, K., M. Tada, T. Kimata, S. Harada, Y. Fujii, T. Mizuguchi, N. Mori, and H. Emori. 1991. Development of new nitrogen removal system using nitrifying bacteria immobilized in synthetic resin pellets. *Water Sci.Tech.* 23:681-690.

Vanotti, M.B., and P.G. Hunt. 2000. Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets. *Transactions of the ASAE* 43(2):405-413.

Vanotti, M.B., A.A. Szogi, P.G. Hunt, P.D. Millner, F.J. Humenik. 2006. Development of environmentally superior treatment system to replace anaerobic swine lagoons in the USA. *Biores. Technol*. (In press).